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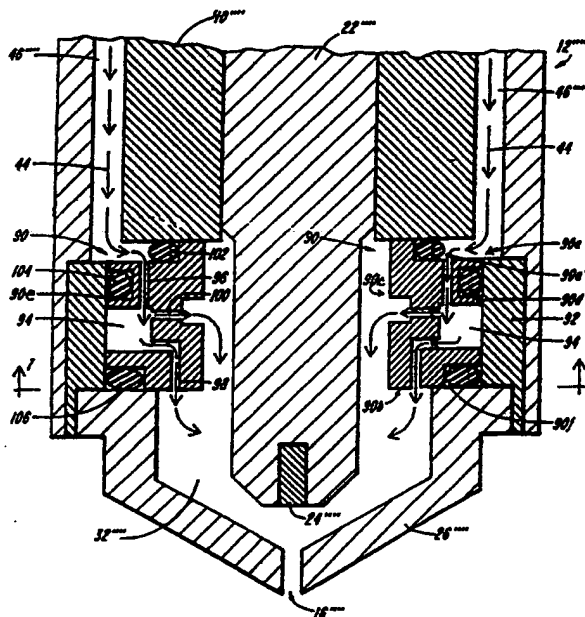
(54) Title: SWIRL RING AND FLOW CONTROL PROCESS FOR A PLASMA ARC TORCH

(57) Abstract

A process and apparatus for reducing wear of an electrode in a plasma arc torch (14) involves providing a substantial pressure drop in a flow of plasma gas from the torch to a plasma arc chamber (32) defined by the electrode (22) and a nozzle (26). The pressure drop is immediately before the plasma arc chamber (32). There is also a small, localized supply of the plasma gas located between the pressure drop and the plasma chamber. The supply is sufficient to stabilize the arc when the gas flow is cut off upstream of the pressure drop and the arc current is cut off very shortly thereafter. The pressure drop is small enough to permit an adequate flow of plasma gas to the plasma arc chamber (32) during normal operations, but large enough to isolate residual gas in the torch from the plasma arc chamber when the arc current is cut off. The apparatus is preferably a swirl ring (28) with an annular pre-chamber (42) fed by a set of choke holes to feed gas to the chamber and create the pressure drop. A set of swirl holes (30) feed gas from the pre-chamber (42) to the plasma arc chamber (32).

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SWIRL RING AND FLOW CONTROL PROCESS
FOR A PLASMA ARC TORCH

Reference to Related Applications

       This application is a continuation-in-part of
U.S. application Serial No. 07/513,780 filed on April
24, 1990.

Background Of The Invention

       This invention relates in general to plasma
arc cutting and welding processes and apparatus. More
specifically, it relates to a process and apparatus
for reducing electrode wear, particularly in high
power torches.
       Plasma arc torches have a wide variety of
applications such as the cutting of thick plates of
steel and the cutting of comparatively thin sheets of
galvanized metal commonly used in heating, ventilating
and air conditioning (HVAC) systems. The basic
components of a plasma arc torch include a torch body,
an electrode (cathode) mounted within the body, a
nozzle (anode) with a central exit orifice, a flow of
an ionizable gas, electrical connections, passages for
cooling, and arc control fluids, and a power supply
that produces a pilot arc in the gas, typically
between the electrode and the nozzle, and then a
plasma arc, a conductive flow of the ionized gas from

the electrode to a workpiece. The gas can be
non-reactive, e.g. nitrogen, or reactive, e.g. oxygen
or air.

Various plasma arc torches of this general
type are described in U.S. Patent Nos. 3,641,304 to
Couch and Dean, 3,833,787 to Couch, 4,203,022 to Couch
and Bailey, 4,421,970 to Couch, 4,791,268 to Sanders
and Couch, 4,816,637 to Sanders and Couch, and
4,861,962 to Sanders and Couch, all commonly assigned
with the present application. Plasma arc torches and
related products are sold in a variety of models by
Hypertherm, Inc. of Hanover, New Hampshire. The MAX
100 brand torch of Hypertherm is typical of the medium
power torches (100 ampere output) using air as the
working gas and useful for both plate fabrication and
HVAC applications. The HT 400 brand torch is typical
of the high power torches (260 amperes) often using
oxygen as the working gas. High power torches are
typically water cooled and used to pierce and cut
thick metal sheets, e.g. 1 inch thick mild steel plate.

In all plasma arc torches, a common and
heretofore unsolved problem has been a substantial
wear of the electrode, particularly when the electrode
is used with reactive gases such as oxygen or air.
(Improved wear, other conditions being the same, is
observed when using non-reactive gases such as
nitrogen or argon as the plasma gas, but the
performance using pure oxygen is superior at least
when used to cut certain materials such as mild
steel. Similarly, air is superior to pure oxygen with
respect to wear, but there is again a performance
trade off.) As an example of this wear problem, the

standard electrode for the MAX 100 brand torch of
Hypertherm, Inc. shows wear as a generally concave pit
on the lower end of the electrode, or more precisely,
on an emitting element of hafnium mounted on the
electrode. On average a wear depth of about 0.025
inch is observed in such a Hypertherm brand electrode
after 120 cut cycles operating with oxygen or air.
The wear results of commercially available units of
others, as measured by Hypertherm, Inc., are typically
worse. For the MAX 100 brand torch, when the wear
produces a pit depth of 0.060 inch or more,
Hypertherm, Inc. recommends that the electrode be
replaced. In ordinary use, the electrode of a plasma
arc cutting torch operating with reactive gases
typically requires replacement after 0.5 to 2 hours of
use depending strongly on the number of on-off
cycles. Wear considerations are significant not only
because they necessitate the repeated replacement of a
component, but also because they limit the maximum
power that can be applied to a given torch. With
particular reference to the present invention, it has
proven especially difficult to control electrode wear
in high current torches, e.g. the water cooled torches
sold by Hypertherm, Inc. under the trade designation
HT 400 and PAC 500, respectively.

        In plasma arc cutting, it is also important
to note that the quality of the cut is highly
dependent on the flow pattern of the gas in a plasma
chamber, defined at least in part as the region
between the electrode and the nozzle. In particular,
a swirling flow produced by injecting the gas
tangentially into the plasma chamber has been found to

be essential to produce a high quality cut. A
swirling gas flow pattern is also important in
stabilizing the plasma arc so that it exits the torch
to attach to and cut the workpiece, but does not
contact the torch nozzle itself. The nozzle is the
principal component that is damaged by the arc when
the arc is not well controlled. Heretofore the
swirling gas flow is often produced mainly by a swirl
ring that has angled holes formed in the ring that
feed a swirling gas flow to the plasma chamber. The
aforementioned U.S. Patent No. 4,861,926, also
describes a swirling secondary cooling gas flow
passing between the nozzle and a surrounding shield
member to assist in the arc stabilization.

Another design consideration is the very high
temperatures of the plasma, e.g. greater than
10,000°C. These temperatures introduce corresponding
changes in the gas properties such as its density and
viscosity. These considerations are significant on
start up and cut-off. On start up the arc rapidly
heats the gas which significantly decreases the gas
density exiting the nozzle orifice. This presents the
situation where the gas flow is choked in the nozzle
orifice region. This choking is, in general,
advantageous during cutting since it restricts the
flow of gas from plasma chamber to atmosphere and
thereby maintains an elevated gas pressure level in
the plasma chamber that constricts the arc. This
leads to an improved cut. A typical gas pressure in
the plasma chamber to achieve these beneficial effects
in a medium to high power torch is about 40 psig. On
cut-off of the arc current, the situation reverses and

there is a tendency for the gas in the plasma chamber
to cool and blow out of the chamber very suddenly.

It is common industry practice to use hafnium
or zirconium as the cathodic emitter insert in the
electrode. Hafnium, as of today, is the best choice
for the cathodic emitting element when cutting with a
reactive gas plasma. It exhibits the least wear of
all other materials tried for this application, but is
more costly than other materials. These electrodes
nevertheless require frequent replacement. Lower wear
has been associated with lower current levels, but at
some point the reduction in performance associated
with a reduced operating current becomes too great.
Cooling the electrode has also been used to increase
electrode life, whether by way of a gas flow or water
flow placed in good thermal communication with the
electrode. However, water cooling is expensive,
cumbersome and is not desirable for low current units,
e.g. those rated below 100 amperes. Air cooling is
less efficient and limits the maximum operating
current of the torch, even one carrying a
comparatively low current. Therefore, to date, the
only practical solution to the electrode wear problem
has been to replace the entire electrode again and
again, despite the clear economic disadvantages of
this approach.

It is therefore a principal object of the
present invention to reduce the wear on the electrode
of a plasma arc torch significantly and thereby extend
its life.

Another principal object of this invention is
to reduce electrode wear and thereby allow operation

at higher current levels than are presently feasible,
even when operating with reactive gases.

Still another principal object of this
invention is to provide a swirl ring which in addition
to producing a swirling output of the gas also
controls the gas flow to the plasma chamber and the
distribution of the gas in the plasma chamber.

Another object of the invention is to achieve
a better cut quality than has heretofore been possible
by allowing a greater level of swirl.

Another object of the invention is to provide
the foregoing advantages while using standard
electrode and nozzle constructions and without any
significant increase in the incidence of damage to
torch parts such as nozzle gouging.

Yet another object of the invention is to
provide the foregoing advantages for existing plasma
arc torch systems using only comparatively simple and
inexpensive modifications.

A still further object is to provide the
foregoing advantages at a favorable cost of
manufacture and operation.

Summary of the Invention

A plasma arc cutting torch, particularly one
using a reactive gas and employed in cutting metallic
materials, has a torch body that mounts an electrode
and a nozzle in a spaced relationship to define a
plasma chamber therebetween. An ionizable gas is fed
by an inlet system which can consist of tubes,
passages and/or chambers to and through the torch body

to a swirl ring mounted in the torch body. The swirl
ring feeds the gas to the plasma chamber in a swirling
flow pattern where it is ionized and exits the torch
via a central exit orifice formed in the nozzle. The
torch also includes standard electrical connections to
a power supply and an electrical controller to
initiate a pilot arc in the gas in the chamber and
then transfer the arc to a workpiece for cutting or
other operations.

The swirl ring of the present invention is an
annular member mounted in the torch body adjacent the
electrode, the nozzle and the plasma chamber. It is
typically secured between the torch body and the
nozzle. The swirl ring includes a pre-chamber,
preferably an annular recess extending around the
outer surface of the swirl ring. A set of choke
passages are formed in an upstream face of the swirl
ring to conduct gas from the gas inlet system in the
torch body to the pre-chamber. The number,
distribution and size of these choke passages restrict
the gas flow and thereby introduce a gas pressure drop
on the feed line immediately before the plasma
chamber. The plasma gas exits the pre-chamber to the
plasma chamber via a set of angled holes found in the
downstream face of the swirl ring. In the preferred
form the swirl ring also includes a set of radial
outlet holes leading from the pre-chamber to the
plasma chamber.

The swirl ring includes annular recesses for
o-rings that seal the swirl ring to the torch body at
its upstream face, to the nozzle at its downstream
face, and to a current ring or other surrounding torch

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component at its outer lateral face. In the preferred
form the pressure drop along the gas inlet holes to
the swirl ring is about 32 psi when the plasma reaches
steady state and the gas pressure in the plasma
chamber is about 40 psi.

This gas control swirl ring is particularly
useful when the electrode wear is further controlled
by altering the mass flow rate of the gas, and/or its
flow pattern, immediately before and immediately after
the step of cutting off of the current to the torch.
The mass flow rate is reduced by either closing off or
reducing the gas flow to the plasma chamber. This
mass flow rate reduction is timed to occur within a
few hundred milliseconds before the current cut off,
and preferably continue after cut off. The process
step of cutting the arc current can be accomplished by
a sudden step function of time or a gradual ramp
function of time. The reduction in the gas flow may
be coupled with a venting of the plasma chamber to
atmosphere to facilitate a more rapid change in the
gas flow pattern in the plasma chamber.

The present swirl ring with gas control
invention can also be viewed as a process
characterized principally by the creation of a
pressure drop in the gas feed line to the plasma
chamber at a point immediately before the plasma
chamber. This pressure drop is sufficiently low that
at steady state operation the arc is stable and well
controlled. The pressure drop is also sufficiently
high that when the gas flow to the torch is cut off,
the gas flow through the plasma chamber is also cut
off rapidly. This limits a sudden and large outrush

of gas from the plasma chamber as the arc extinguishes and the plasma gas cools. The process includes providing a small localized source of gas immediately adjacent the plasma chamber so that there is sufficient gas available to the plasma chamber to maintain control over the arc after the gas flow is cut off, but before the arc is fully extinguished and could otherwise damage the torch. These process features can also be achieved by placing the aforementioned flow restrictions and pre-chamber in a torch component or components other than the swirl ring, such as a portion of the torch body adjacent the plasma chamber.

These and other features and objects of this invention will be more fully understood from the detailed description which should be read in light of the accompanying drawings.

Brief Description Of The Drawings

Fig. 1A is a simplified schematic view of a prior art typical plasma arc torch connected to a gas flow control that controls the gas flow to the torch to reduce electrode wear;

Fig. 1B is a view in horizontal section along the line 1B-1B in Fig. 1A;

Fig. 1C is a simplified schematic view of a plasma arc cutting system using the torch shown in Figs. 1A and 1B;

Fig. 1D is a six graph timing diagram of the gas flow alteration in relation to the cut-off arc current that has been found to extend electrode life;

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Figs. 2A, 2B and 2C correspond to Figs. lA, lB and lC and show an alternative arrangement for electrode wear reduction utilizing a valved vent in combination with a valved gas feed;

Figs. 3A, 3B, 3C, and 3D correspond to Figs. 2A - 2C, Figs. 3B and 3C corresponding to Fig. 2B, and show an alternative arrangement utilizing axial and radial inlet hole sets in a swirl ring to establish either swirled or axial gas flow patterns in the plasma chamber;

Fig. 4 is a simplified schematic view corresponding to Fig. lC showing flow control mechanisms in the gas supply line to provide a preflow and ramp up of the flow on start up as well as a ramp down on cut off;

Fig. 5 is a five graph timing diagram of the gas flow alteration on start-up;

Fig. 6 is a simplified view in vertical section of a swirl ring with a gas control function according to the present invention mounted in a plasma arc torch of the general type shown in Figs. lA, lC, 2A, 2C, 3A, 3D and 4, with the upper portions of the torch body broken away and other components, such as a retaining cap, omitted;

Fig. 7 is a bottom plan view of the swirl ring only shown in Fig. 6 taken along the line 7-7; and

Fig. 8 is a graph plotting the gas pressure in the plasma chamber of the torch shown in Fig. 6 as a function of time during one cycle of operation and also plotting the arc current carried by the plasma over the same cycle of operation.

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Detailed Description Of The Preferred Embodiments

        Figs. 1A and 1B show in simplified schematic
form a typical plasma arc cutting torch 12 such as any
of a variety of models of torches sold by Hypertherm,
Inc. The immediately following description is
therefore intended to illustrate the basic principles
and elements common to plasma arc cutting torches of
this type, but not to describe construction details of
any particular torch model. The torch has a body
indicated generally at 14 which typically is
cylindrical with an exit orifice 16 at one end, the
lower end 12a as shown, through which a plasma arc 18,
an ionized gas jet, passes and attaches to a metal
workpiece 20 which is being cut. The gas can be
non-reactive, such as nitrogen or a noble gas, but it
can also be reactive, such as oxygen or air. A
significant advantage of the swirl ring and associated
gas control process of the present invention is that
the torch can operate with a reactive gas and
nevertheless have dramatic improvement in electrode
wear even when operating at high power levels.
        The torch body 14 supports a cathode 22,
commonly referred to as an electrode, which is
typically made of copper and has a generally
cylindrical configuration. An emitting element 24 is
press fitted into the lower end face of the electrode
22. The electrode and the emitting element are
centered within the torch body and aligned with the
exit orifice 16. When using a reactive gas, the
insert is typically formed of hafnium or zirconium.
The body 14 also mounts a nozzle 26 with a central

nozzle orifice that defines the torch exit orifice
16. The nozzle is spaced from the electrode. A swirl
ring 28 of conventional construction and having a set
of radially offset gas distribution holes 30 is
replaceably mounted in the torch body. It is
positioned to feed a flow of the plasma gas from the
holes 30 to a plasma arc chamber 32 defined, as shown,
by the electrode, the nozzle and the swirl ring.

     With this prior art conventional swirl ring
the offset of the holes, best seen in Fig. 1B,
introduces a tangential velocity component to the gas
flow through the chamber 32 causing it to swirl. With
the electrode wear reduction advantages described
herein, the level of swirl introduced by these holes
can be greater than has heretofore practicable
resulting in a better cut quality than has heretofore
been attainable. The swirl ring is shown in a tight
fitting, gas sealed relationship to the electrode. It
will be understood, however, that the swirl ring is
often mounted in a support member and does not itself
seal to the electrode. More generally, the particular
construction details of the torch body and
arrangements for mounting these elements directing gas
and cooling fluid flows and providing electrical
connections can and do take a wide variety of forms.

     A negative power lead 34 surrounds the upper
end of the electrode 22 to make a good electrical
connection. A retaining cap 36 threads onto a current
ring 38 that forms the upper end of the torch body
14. An insulator sleeve 40 separates and electrically
isolates the current ring 38 from the negative power
lead 34. The retaining cap has a lower lip 36a which

engages a flange 26a on the nozzle in an abutting
relationship. The retaining cap when tightened onto
the ring 38 captures and replaceably secures the
nozzle against the swirl ring. In an alternative
construction not shown, it can also capture and secure
the swirl ring between the nozzle and another internal
support structure within the torch body. In the
configuration shown, the retaining cap 36 also, in
part, defines a gas plenum chamber 42 that acts as a
local supply to the swirl ring 28 and the plasma
chamber 32. A flow 44 of plasma gas passes through an
inlet tube 46 which penetrates the current ring 38 to
feed the gas to the plenum chamber 42. A solenoid
valve 48 such as Model No. AFP33183 manufactured by
Automatic Switch Company is secured in the inlet tube,
preferably at a point closely spaced from the torch
body. Control signals to the valve over lines 48a,48a
open and close the valve to regulate the flow rate of
the gas to the torch. In a pilot arc mode of
operation, where a pilot arc is drawn between the
electrode and the nozzle through the gas in the plasma
chamber, the nozzle acts as an anode and the cap 36
and current ring 38 form a pilot arc current return
circuit.

In operation, plasma gas 44 flows through the
solenoid valve 48 and the inlet tube 46 into the
plenum chamber 42. From there, it flows through the
gas distribution holes 30 in the swirl ring 28 into
the plasma arc chamber 32 and finally out of the torch
through the nozzle orifice 16. When the torch is
operating in the nontransferred pilot arc mode, a
power supply 50 provides current to the torch at an

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appropriate voltage to initiate the pilot arc and then
maintain it. The power supply can be any conventional
regulated D.C. supply and includes a p.c. board or the
like which controls the operation of the power supply
and other components of the torch system such as flow
control valves.

　　　　　With reference to the complete plasma arc
cutting torch system 52 depicted in Fig. 1c, the
complete current path in the nontransferred pilot arc
mode is from the negative power supply terminal 50a,
through lead 54, the negative power lead 34, electrode
22, a pilot arc plasma 56 (Fig. 1A), the nozzle 26,
the retaining cap 36, the current ring 38, a pilot arc
return lead 58, a closed pilot arc switch 60, and a
power supply positive terminal 50b. When the torch 12
is lowered toward the workpiece 20, the arc transfers
to the workpiece as the ionized plasma jet 18. This
allows some current to flow from the workpiece through
a ground lead 62 back to the power supply positive
terminal 50b. When this transferred current path is
established, the pilot arc switch opens and the torch
is cutting the workpiece. In this transferred or
cutting mode, the current path is from the power
supply negative terminal 50a, the lead 54, negative
power lead 34, electrode 22, the plasma arc or jet 18,
the workpiece 20, the ground lead 62 and the power
supply positive terminal 50b.

　　　　　An operator sets a desired gas flow or
pressure associated with full power operation in a
transferred arc mode prior to initiating the pilot arc
at a control console 64 which is removed from the
torch itself. The console includes gas flow

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regulators, gas valving, and pressure gauges. The
flow and pressure values set by the operator at the
console correspond in a known way to the actual gas
flow and pressure in the plasma chamber 32 prior to
the pilot arc. Starting the pilot arc heats the gas
causing an increase in the gas temperature within the
chamber and a decrease in the flow, in a manner well
known in the art. A typical gas pressure in the
chamber 32 during the pilot arc is 20 to 40 psi. For
high power torches which are the particular focus of
the present invention, the gas pressures are usually
at or near 40 psi. The pilot arc is started by a
high-frequency spark or other means, such as a contact
starting technique, all of which are well known in the
art. During start up the plasma gas 44 flows through
the tube 46, solenoid valve 48, plenum chamber 42,
swirl holes 30, the plasma chamber 32 and out the exit
orifice 16. As noted above, the swirling flow
established by the holes 30 is very important in
obtaining a good quality cut and in stabilizing the
arc within the nozzle exit orifice 16 — to prevent
the arc from impinging on the nozzle and gouging it.
As will be discussed in detail below, the operational
life of the electrode can be increased further by
utilizing a novel start up procedure and the apparatus
illustrated in Figs. 4 and 5 and the novel swirl ring
and associated gas flow control functions described
with reference to Figs. 6-8.

Also as noted above, the torch begins cutting
when it is brought close to the workpiece so that the
arc transfers to the workpiece and the controller
opens switch 60. After transfer, in normal operation

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the controller increases the current level to a
predetermined value for cutting. This increase in
current also results in an increase in the heating of
the plasma gas, a further increase in the gas pressure
in the plasma chamber, and a further decrease in the
gas flow out of the nozzle exit orifice. The maximum
recommended current levels vary greatly among
different torches and applications, with currents in
the range of about 20 to 200 amperes D.C. being
characterized as low currents and those 200 and above
being high currents. A typical current level for a
water cooled cutting torch used to cut plate steel is
260 amperes.

     A discovery of applicants is that a
significant loss of material (wear) of the electrode
during its operation occurs not during the actual
cutting, but rather when the current to the arc is
shut off. While the mechanisms for this wear are not
fully understood, there is evidence that the electrode
becomes molten, at least in part, during operation and
that on cut-off of the electrical power wear is
related to a complicated interaction between the
molten surface(s) of the electrode and the flow and
pressure of the plasma gas through the plasma chamber.

     The swirl ring and associated gas flow
control process of the present invention builds on
applicants' discovery that a control of the plasma gas
flow to the plasma chamber in conjunction with a
controlled electrical shut off to reduce electrode
wear substantially. In its simplest form, this wear
reduction involves a total shut off of the plasma gas
flow to the chamber 30 just before (1) a total, step

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function shut off of the arc current or (2) at the
same time the arc current starts a gradual shut off,
but also just before a total shut off of the arc
current. This effect is achieved by closing the
solenoid valve 48 just prior to the total shutting off
process of the arc current. The preferred process for
shutting off the current is a controlled linear
decreasing ramp which follows the decreasing mass
flow. The timing of these shut offs is, however,
critical. If the gas flow is allowed to decrease
rapidly, there is a significant diminution of the
swirling plasma flow that stabilizes the arc.
Therefore the arc can and will attack and damage, or
even destroy, the nozzle in a very short time. On the
other hand, if the shut-offs are too close in time,
the gas flow and pressure in the chamber 30, which
decay in a generally exponential manner with the valve
48 shut, exhibit little change and wear occurs to
about the same extent as if the valve 48 was left
open. The gas flow shut off continues through the arc
current shut off, and thereafter.

The timing of the gas and current shut off
processes are illustrated by the timing diagrams of
Fig. 1D. The three lefthand graphs show the control
signals (whether a voltage signal, current signal, or
otherwise) as a function of time. The first lefthand
graph shows a control signal (applied over lines
48a,48a) to the solenoid valve 48 changing its state
at a time t_1 (the signal goes from a "1" state to a
"0" state which are indicative of either a digital
switching or an analog change sufficient to produce
the desired change in state of the valve 48). This

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change in the control signal closes the valve at
t_1. The second lefthand graph shows a control
signal for the arc current, a signal generated by the
controller of the power supply 50. The arc current
control signal changes its state, again shown as a
change from a "1" state to a "0" state, at a time t_2
which is after time t_1. The gas flow is therefore
cut off before the arc current by a time interval Δt
equal to the difference between t_2 and t_1. The
third lefthand graph shows an alternative control
sequence for the arc current cut-off process. In
accordance with this invention the arc current control
signal changes its state, again shown as a change from
a "1" state to a "0" state, at a time t_1 which is
the same time as the valve control signal. This
change commences the operation of the controller to
produce a ramp down of the arc current as shown in the
lowermost righthand graph of Fig. 1D.

The righthand graphs in Fig. 1D show: 1) the
gas flow rate through the plasma chamber 32; 2) the
arc current shut off process as a sudden step off at
t_2; and 3) an alternative arc current shut off
process as a gradual linear ramp down from full
current at t_1 to a minimum sustainable current at
t_2 when the arc current snuffs out to zero. These
graphs are also presented as a function of time and
for the same periods of time as the corresponding
lefthand graphs. After closing the valve 48 at t_1,
the gas flow falls steadily. A generally linear fall
off in flow is shown, but the relationship is actually
more complex and the curve is in fact generally
exponential. The important factor is that the gas

flow value falls substantially over the internal Δt
so that a) it is at a comparatively low value at t_2
when the arc current is shut off, as illustrated by
the second righthand graph of Fig. 1D, or b) it is a
comparatively low value at t_2 following the current
ramping down illustrated by the third righthand graph
of Fig. 1D. The presently preferred arrangement is to
use a non-vented ramp down of the gas flow as shown in
the upper righthand graph in combination with an arc
current ramp down as shown in the lower righthand
graph that follows the change of the gas flow over the
time interval Δt. This preferred mode of operation
seems to produce the least wear despite the fact that
a lower arc current changes the gas density in a
manner that produces an increased gas flow rate
through the plasma chamber -- other factors being
constant. The swirl ring described below with respect
to Figs. 6-8 addresses the problem of this increased
gas flow rate.

While the precise value of Δt varies with
each torch and the particular operating parameters,
for most low current plasma arc cutting applications a
Δt of 500 milliseconds or less has been found to be
the right timing to reduce electrode wear. For the
MAX 200 brand torch, a Δt of roughly 250 to 300
milliseconds without venting and with a following
current ramp down has been found to be optimal. In
the operation of a MAX 100 brand torch after 120 cut
cycles using this gas flow/arc current control there
is a pit depth (wear) of about 0.005 inch, whereas
normal operation without these controls produces a
wear depth of about 0.025 inch in the same electrode

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insert 24.   This wear reduction translates into an
electrode life which is five times the best value that
has ever before been attainable. This gas flow/arc
current control may also allow, on average, torches to
be operated at powers in excess of their conventional
ratings.

Note that at t_2 there is still a residual
gas flow even though the gas feed is cut off at t_1.
This ensures that until and at current cut-off there
is a sufficient flow in the chamber to stabilize the
arc and prevent nozzle damage. Also, there is a brief
surge in the flow after cut-off of the current. This
is believed to reflect a sudden cooling of the gas in
the absence of the arc and a rapid out-flow of gas
from the torch driven by the gas pressure in the
plasma chamber and the sudden change in the properties
of the gas after the arc is extinguished. This rapid
out-flow can be analogized to an explosive
decompression. It is particularly troublesome in the
high power torches.

This out-flow phenomena suggests that while
the gas flow to the torch can be reduced over the
interval Δt by reducing the flow 44 to the plasma
torch, that a complete closure of the valve 48 is
preferred since this closure upstream of the plasma
chamber dampens the strength of the flow surge and
limits the total volume of the flow when the current
is cut-off. As already stated, it is also
contemplated to reduce the current at t_1, e.g. by
ramping it down over the interval Δt rather than
having an abrupt shut off at t_2. It is also
contemplated to allow a reduction in the overall

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current prior to t_1, or after t_1, i.e., prior to
or after closing the solenoid valve.

Figs. 2A-2C show the plasma arc cutting torch
12' incorporating an alternative gas flow control
arrangement to reduce electrode wear, like parts in
the Fig. 2A-2C embodiment having the same reference
numbers as in Figs. 1A-1C, but with a prime. The
structure and mode of operation of the torch 12' and
torch system 52' is the same as described above with
respect to the Figs. 1A-1C embodiment, except for the
addition of a vent tube 66 and an associated solenoid
valve 68 connected in the vent tube to open and close
it. The tube 66 penetrates the current ring 38' and
is in fluid communication with the plenum chamber
42'. A control signal from the controller carried
over lines 68a,68a operates the valve 68. In this
embodiment, when the solenoid valve 48 is closed at
time t_1. The vent valve 68 is opened. Because the
vent tube 68 is open at its end 66a at atmosphere, or
to some other lower pressure region such as a vacuum
chamber, opening the valve 68 causes the gas flow and
pressure in the plenum and the plasma chamber to decay
more rapidly than the decay of the Figs. 1A-1C
embodiment. This allows the current to be shut off
more quickly after the gas flow is cut-off at time
t1. It has been discovered, however, that timing is
very important in this configuration. Since by
venting an alternative flow path is established, the
flow through the nozzle can go to low values and cause
the plasma to become unstable very quickly. In
general, when venting is used the flow alteration
preceeds the arc current shut off by a significantly

short period of time and without venting. With this
venting, the interval Δt can be reduced from about
250 milliseconds to less than 5 milliseconds when
operating a MAX 200 brand torch with air. This may
reduce the likelihood of nozzle damage caused by a
destabilized arc. It is also contemplated that valves
48' and 68 can be combined in a single venting-type
valve.

Figs. 3A-3D show another embodiment of a
torch 12" and torch system 52" utilizing according to
the present invention, like parts being identified
with the same reference numbers, but double primed.
This embodiment utilizes the discovery that electrode
wear can be reduced substantially if the gas flow
through the plasma chamber is changed not only in flow
rate, but also in flow pattern, just prior to current
shut off. More specifically, electrode wear is
reduced to almost negligible levels on current shut
off if the degree of swirling of the gas is reduced
just before cut-off. At moderate gas pressures, this
result holds for even high gas flow rates (e.g. 120
scfh). In operation with the Hypertherm® MAX 100
brand torch, negligible wear was observed when the gas
flow into the plasma chamber was radial (no swirl) and
the gas pressure in the chamber was below 30 psi.
While a perfectly radial flow and moderate to low gas
pressures produce the best results, this arrangement
also provides reduced electrode wear with less than a
perfectly radial flow and at increased gas pressures.
In this embodiment a major concern once again is
destabilization of the plasma arc in the absence of a
swirling flow. Applicants' solution is to use a

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swirling flow, and then suddenly switch to a radial
flow, with substantially no interruption of the
overall flow rate, immediately before current cut
off. The torch 12" and system 52" accomplish this
mode of operation.

The torch 12" has generally the same
construction as the torches 12 and 12', except that
the torch is serviced by two separate gas feed lines,
each with its own solenoid valve, which feed separate
plenum chambers and in turn feed separate, independent
inlet holes in the swirl ring 28" or an equivalent
structure. In the preferred form shown, there is a
first gas flow 44c which passes through the inlet tube
46", the valve 48", an annular plenum chamber 42", the
inlet holes 30", the plasma chamber 32" and out the
exit nozzle orifice 16". This gas flow path provides
a swirling gas flow for cutting that produces a good
quality cut and stabilizes the arc. The swirl is
established by the holes 30" which are radially offset
as is best seen in Fig. 3B. The plenum chamber 42" is
defined by the same components as in previous
embodiment except that the current ring has an annular
downwardly extending wall 38a" and a flange 38b" at
the lower edge that abuts a step recess in the swirl
ring 28" in a gas tight seal. (It will be understood
that the seal can be secured with O-rings, a labyrinth
seal, or any conventional gas seal that also allows
the swirl ring to be disassembled from the torch as
necessary.) The wall 38a" and flange 38b" separate
and isolate from one another the outer plenum chamber
42" and an inner plenum chamber 42d".

A gas flow 44d passes through an inlet tube

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46d", a valve 48d", the plenum chamber 42d", inlet
holes 30d", the plasma arc chamber 32" and out the
exit nozzle orifice 16". This second gas flow path
for the flow 44d uses inlet holes 30d" in the swirl
ring that are generally radially directed as is best
seen in Fig. 3C. The gas flow through the plasma
chamber is therefore generally axial (downwardly as
shown) through the chamber 32" to the exit 16"; there
is substantially no swirl.

  In accordance with this flow pattern altering
process for electrode wear reduction, at a
predetermined but very brief interval Δt before the
current to the torch is cut off, the controller closes
the valve 48" for the flow 44c and opens the valve
48d" for the flow 44d. The interval Δt for a MAX
100 brand torch operating with a reacting gas is
typically less than 500 milliseconds. This change in
flow pattern, with no other changes in flow or current
parameters, has also been found to provide dramatic
reductions in electrode wear. However, this
embodiment can be combined with the mass flow rate
reduction embodiment described above with respect to
Figs. 1A-1D and 2A-2C. For example, the current level
can be ramped down after t_1.

  Fig. 3D shows a suitable system 52" for
practicing the invention in this altered flow pattern
mode. A control console 64" remote from the torch and
therefore the substantial electromagnetic interference
produced by the torch, controls the gas flow 44c. A
like console 64a" controls the flow 44d. In practice
the consoles 64" and 64a" can be a single unit.

  While various time periods have been

suggested above for Δt, the optimal interval will
depend on the specific torch, its applications, and
related parameters. In general, Δt is a function of
the type of gas, the current level, size of nozzle
orifice, inlet flow area of swirl ring, the gas
pressure, the gas flow rate, the gas flow pattern, and
the physical separation between the solenoid valves in
the inlet and vent tubes and the plasma. The
separation is preferably less than 12 inches for the
MAX 100 brand torch. This separation helps to control
delays and unintended variations in flow parameters
due to the presence of a large fluid mass upstream of
a plasma chamber and downstream of the valve. The
values for an acceptable interval Δt can readily be
determined empirically. Also, while the invention as
described thus far has focused on the alteration of
the gas flow just prior to cut off, it should be
understood that the altered condition continues
through electrical cut-off and for a brief period
thereafter. However, the flow usually ceases entirely
very shortly after cut-off, whether due to a closing
of the solenoid valve in the inlet tube which
eventually brings the flow through the plasma chamber
to zero, or through a closing of the valve 48d" in the
"radial" gas flow path to the radial hole 30d" in the
Fig. 3A-3D embodiment.

Fig. 4 shows yet another embodiment of a
torch 12'" and a torch system 52'", like parts being
identified with the same reference number, but triple
primed. This embodiment is like the embodiment shown
in Figs. 1A-1D except that it has two sources of
plasma gas connected via tube 78 and on-off solenoid

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valve 48'" to the inlet tube 46'" which in turn
directs the gas to the interior of the torch 12'" and
its plasma chamber. A preflow gas flow 44f flows
through the preflow remote console 84 including an
orifice 84a, a pressure gauge and a flow meter. The
preflow passes through conduit 82 and a preflow on-off
solenoid valve 80 into a branch conduit 78a and then
into a gas feed tube 78. An operating plasma gas flow
44'" flows through the operating flow remote console
74 including an orifice 74a, a pressure gauge, and a
flow meter. The operating gas flow 44'" then passes
through a conduit 72 and an on-off solenoid valve 70
into a branch conduit 78b, and then into the gas feed
tube 78. The two soruces of plasma gas are connected
in parallel via branch tube 78a and branch 78b to the
feed tube 78.

A further discovery of applicants is that
significant electrode wear can occur on start up as
well as cut off. In particular it has been found that
alteration of the gas flow to the torch on start up
can make substantial improvements in the electrode
life even as compared to the substantial improvements
achieved with the cut off controls described above
with respect to Figs. 1A-3D. Specifically, the start
up procedure and apparatus described below in detail
have been found to double the life of electrodes when
also using the cut-off procedure and apparatus
described with reference to Figs. 1A-3D. An electrode
life about 10 times than that obtainable using prior
art procedures and equipment is readily obtainable.

The solenoid valves operate automatically in
response to control signals produced by the power

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supply and directed to the valves over lines 86a, 86b
and 86c. The valves 48'", 70 and 80 can also be
solenoid feed valves of the type described above with
respect to valve 48. The flow orifices 84a and 74a
can be adjusted manually or automatically.

In operation, to start the torch 12'"
according to the present invention, a preflow 44f of
the ionizable gas is directed from the source to the
torch. The preflow is at a significantly lower flow
rate and pressure that the gas flow rate and pressure
associated with full power operation when the arc has
transferred to a workpiece.

With reference to Fig. 5, the start of the
plasma torch is indicated at t_0. A control signal
initiated by the operator causes signals to be sent
over lines 86a and 86c to open valves 48'" and 80
respectively, but maintain valve 76 in a closed
condition. All of the gas flow to the torch therefore
passes through, and is limited by, the adjustable
orifice 84a. It is set to establish a gas mass flow
rate that is (i) sufficient to initiate and sustain a
pilot arc in the torch 12'", but also (ii)
sufficiently below the full operating value in the
transferred arc mode that the improved wear
characteristics of the present invention are
observed. By way of illustration, a full flow rate
can be 40 scfh for a Hypertherm® MAX 100 brand torch
and the preflow can be 24 scfh, or about 60% of the
full flow. The precise value for the preflow will
vary depending on the factors such as those enumerated
above with respect to the timing of the altering of
the gas flow on cut off, but it will be within the

functional "end limits" given above, that is, being
able to ignite a pilot arc while exhibiting the wear
improvement of the magnitude described herein. The
middle graphs in Fig. 5 reflect valves 48'" and 80
opening at t_0. The top graph reflects an increase
in the gas pressure in the plasma chamber as a result
of the preflow through these valves.

Time t_1 in Fig. 5 reflects the time when
the arc transfers to the workpiece and the torch
begins operating in the transferred arc mode. The
time interval t_0 to t_1 is preferably sufficient to
produce a stable preflow. Four seconds is a typical
value for this interval. Just prior to t_1 there is
a small step increase in the arc current, as
illustrated in the second graph from the top in Fig.
5. This current is a standard pilot arc current. The
pilot arc is ignited after the preflow is stabilized
and is maintained for a brief interval before t_1, a
typical value being 20 milliseconds.

At t_1, the transfer of the arc generates
another control signal sent over line 86b to open
valve 70 as reflected in the third graph from the top
in Fig. 5. The power supply also begins to increase
the arc current at t_1 toward a desired full
operating value. At the same time the control signal
86c causes the preflow solenoid valve 80 to close.
The opening of valve 70 allows an increased gas flow
to the torch as reflected by the rise in the gas
pressure at the inlet to the torch as shown in the top
graph in Fig. 5. The orifice 74a sets the maximum
flow to the torch. Due to the lead from the valves to
the plasma chamber, the increase in the gas flow and

pressure is not a sharp step function, but rather a
smooth ramping up, as shown. The increase in the gas
flow is preferably in coordination with the increase
in the arc current, also as shown. The current and
gas flow need not increase precisely in coordination,
but the flow must be increased sufficiently so as to
sustain the transferred arc at the current level then
prevailing. The flow must also swirl and have a
sufficient flow rate to guide the plasma jet and
contain it against attacking the torch itself. This
valve and conduit arrangement also lends itself to the
use of one type of gas as a preflow gas and another
type as the plasma gas in a transferred arc mode.
Preferably a less reactive gas such as nitrogen or
argon is used for the preflow. The switch over from a
preflow to an operating flow attendant opening valve
70 and closing valve 80 on arc transfer allows the
introduction of a more reactive type of gas such as
pure oxygen or air. Alternatively, the preflow can be
air and the operating flow can be oxygen. When this
preflow and ramp up start procedure is used in
combination with the cut-off procedures described
above, the electrode life can readily and reliably be
extended by a factor of about ten.

   While the start up features have been
described with respect to a change in the flow rate
produced by a valve network, the beneficial effects of
an axial gas flow evident on cut off also apply to
start up. A swirling flow is necessary to control the
arc during operation, but at least during the preflow
phase when the pilot arc is ignited, the flow pattern
can be axial to reduce wear, and then switched over to

a swirling flow on transfer at t_1. This change in
flow pattern can be combined with an increase in flow
rate before, at, or after the switch over at t_1.
The apparatus shown in Figs. 3A-3D can be used for
this flow pattern alteration on start up as well as on
cut off.

To end a cycle of operation with the Fig. 4
embodiment and to utilize the cut off advantages
described above, the valves 48'" and 70 can be close
at t_2 causing a decay in the gas pressure and flow.
There is a corresponding decrease in the arc current,
all as described above with respect to Figs. 1A-3D.
At time t_3 the cycle of operation is complete and
the torch is off.

Figs. 6-8 show a novel swirl ring 90
according to the present invention which replaces the
conventional swirl ring 38 shown in Figs. 1A, 1B, 2A,
2B, and 3A - 3C. The swirl ring 90 is particularly
designed for use in conjunction with the gas flow/arc
current controls described above with reference to
Figs. 1A - 4. It is particularly effective in
reducing electrode wear in high power torches such as
the Hypertherm® HT400 and PAC 500 brand torches
where the gas flow/arc control procedures described
above have proven to be less effective than with lower
power torches such as those rated at up to 200 amperes.

It has been discovered that for these high
power torches the gas out-flow on cut-off is
sufficiently strong and of sufficiently long duration
to produce an unacceptable degree of electrode wear
despite the use of the apparatus and processes
discussed hereinabove, despite the location of the gas

cut off valves 48,48' and 48'" close to the torch, and
despite operation with the gas flow being totally shut
off just prior to cut off of the arc current, as
opposed to merely being significantly reduced in flow
rate.

    The swirl ring 90 has been found to overcome
these problems in high power torches and thereby
extend the electrode life to the same extent as
described above with respect to Figs. 1A - 4. The
swirl ring 90 is a generally annular member formed of
a conventional structural material used conventionally
for swirl rings. The preferred material is lava rock,
which is machinable ceramic. The ring 90 has a
generally rectangular cross section, as shown in Fig.
6, with an upstream face 90a in fluid communication
with a gas passage 46"", or an equivalent gas
conducting tube or chamber formed in or secured within
the torch body 12"" (like parts in the Fig 6-7
embodiment being identified with a quadruple prime).
The gas flow 44 to the torch flow is substantially
unimpeded (except for the action of the various valves
and meters described hereinabove) to the upper face
90a. The ring 90 has a lower or downstream face 90b
open to the plasma arc chamber 32"", defined mainly by
the electrode 22"", the nozzle 26"" and the swirl ring
90 itself, as shown. An inner lateral face 90c is
also open to the plasma chamber 32"". An outer
lateral face 90d abuts a surrounding current ring 92
that is in electrical connection with the nozzle
26"".

    A principal feature of the swirl ring 90 is a
pre-chamber 94 formed in the preferred form shown as a

central annular recess in the outer face 90d of the
swirl ring. Another principal feature is a set of
equiangularly spaced choke holes 96 drilled in the
ring 90 and extending from the upper face 90a to the
pre-chamber 94 to provide a fluid passage for the flow
44 from the passage 46"", or a comparable structure,
to the pre-chamber. It is important that the choke
holes 96 are of a number and size that together they
conduct a sufficient flow of the working gas to the
plasma arc chamber to sustain and stabilize the arc
during steady state operation, but at the same time
they are sufficiently restrictive to this flow that a
significant drop appears in the gas pressure across
the holes 96. By way of illustration, but not of
limitation, where the pressure in the plasma chamber
during steady state operation of a high power torch is
40 psi, the pressure drop across the holes 96 is about
32 psi. Also by way of illustration only, for a
nozzle ring suitable for a HT400 brand plasma arc
torch manufactured by Hypertherm, Inc., there are six
choke holes, spaced equiangularly, each having a
constant internal diameter of about 0.018 inch and a
length of about 0.136 inch.

The gas entering the swirl ring and held in
the pre-chamber 94 exits to the plasma chamber via
set of swirl holes 98 drilled at an angle in the lower
face 90b of the ring and a set of radial holes 100
drilled in the inner lateral face 90c. The swirl
holes are equiangularly spaced to facilitate a uniform
flow distribution of the swirling gas in the plasma
chamber. By way of illustration but not of
limitation, there are twenty four swirl holes 98, each

having a diameter of 0.025 inch and angled at 20° from
the vertical to introduce a tangential swirling
component to the gas flow exiting the swirl ring. The
radial holes also extend from the pre-chamber to the
plasma chamber to set up an axial flow of gas to the
plasma chamber. The number and dimensions of the
radial holes 100 is such that they contribute some
axial flow into the plasma chamber during steady state
operation, but it is introduced upstream of the
swirling flow and its flow pattern is overcome by the
swirling flow in normal operation. The radial holes
aid in distributing the gas uniformly through the
plasma chamber, both by contributing a gas flow and by
placing the upper end of the plasma chamber at the
same gas pressure as the lower end, adjacent the swirl
holes 96. By way of illustration but not of
limitation, the radial holes 100 are four in number,
equiangularly spaced, and have at their minimum
diameter the same 0.018 inch diameter as the choke
holes.

In the preferred form illustrated and
described, the swirl ring 90 requires three seals to
provide fluid isolation of the three chambers — the
inlet 46"", the pre-chamber 94 and the plasma chamber
32"". A first o-ring 102 is seated in a shoulder
recess 90a' at the upstream face of the swirl ring; it
blocks a flow of the gas directly from the gas exit
from the torch body to the plasma chamber. The o-ring
102 abuts and seals to a portion 40'" of the torch
body. A second o-ring 104 seated in an annular recess
90e formed on the outer face 90d of the swirl ring
blocks a direct gas flow from the torch body to the

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plasma chamber. The o-ring 104 abuts and seals to the
current ring 92. The o-rings 102 and 104 force the
plasma gas passing through the torch body to pass
through the pre-chamber 94 also. A third o-ring 106
seats in an annular recess 90f in the downstream face
90b to block any leakage of gas exiting the swirl ring
other than through the plasma chamber 32"" to the exit
orifice 16"". The o-ring 106 abuts and seals to the
nozzle 26"".

This swirl ring construction places a
significant flow restriction, the choke holes 96, very
close to the plasma chamber. On cut-off, as the
plasma cools and there is a sudden out-flow of gas,
the pressure drop at the choke holes restricts the
out-flow of the gas held in the torch body and the
relatively short gas conduits spanning the distance
between the control valves 48,48' and 48'" and the
swirl ring. (The closest upstream valve is closed
prior to the arc current cut-off to assist in a rapid
cut-off of the plasma gas flow in the plasma gas
chamber.) The pre-chamber 94 therefore acts as a
small local reservoir of gas to supply the plasma
chamber during the milliseconds between a shut off of
the gas flow and a total cut off of the arc current.
This is important since the simple expedient of
shutting off the gas flow totally prior to arc cut-off
(and allowing the residual gas to be used up in
cutting) allows the arc to become destabilized and
attack the nozzle. The pre-chamber is therefore sized
to supply a volume of gas to the plasma chamber in the
interval Δt between the gas shut off and the arc
current shut off sufficient to maintain the arc in a

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stabilized condition, but not sufficient to exhibit a
degree of electrode wear characteristic of prior art
torches. By way of illustration, but not of
limitation, the pre-chamber 94 has cross sectional
dimensions of about 0.114 inch by 0.187 inch with an
I.D. of about .764 inch and an O.D. of about .996 inch
for use with the HT400 brand torch and with the
illustrative hole dimensions given above.

Fig. 8 is a graph illustrating the gas
control function of the swirl ring shown in Figs. 6
and 7 when also used with the gas flow and arc current
controls on start up and cut-off discussed above for a
Hypertherm® MAX 200 brand plasma arc torch. There
is a preflow of plasma gas on start up to bring the
gas pressure in the plasma chamber to about 4 psi.
Firing a pilot arc raises the pressure to about 12
psi. On arc transfer to a workpiece, the plasma gas
pressure increases further as the valves are opened
and then arc current increases to its full operational
value. At the completion of an operating cycle, the
arc current is ramped down (t $_{cut-off}$) and the
plasma gas flow is shut off at the upstream control
valve 48'". The arc is then stabilized by gas drawn
out of the pre-chamber through the holes 98 and 100,
with the choke holes 96 restricting an inflow of gas
from upstream conduits, passages or chambers in the
torch body. Preferably, as shown, the arc current is
shut off completely when the plasma gas pressure falls
to about 4 psi. Stated in other words, the volume of
gas available for a rapid expansion when the arc cuts
off and the plasma cools is quite small. This allows
the gas control/arc current control procedures

described above to operate and to extend the electrode
life, even for high current torches. The swirl ring
and associated gas flow control features also enhance
the electrode life in low to medium power torches.

Another significant aspect of the swirl ring
90 according to the present invention is that it also
distributes the gas very uniformly due to the size,
number and location of the gas conducting holes 96, 98
and 100 formed in the ring. This is in contrast, for
example, to a possible expedient of simply creating a
restriction in the gas outlet from the torch body to
the plasma chamber. One restriction was found to
create non-uniform, high-velocity gas jets at the
outlet of the restriction which produced a highly
uneven wear on the electrode and reduced the quality
of the cut in the workpiece. A characteristic of the
present invention is that the plasma gas flow pattern·
is substantially independent of the choke holes; it
can be altered using standard techniques used for
conventional plasma arc cutting torches.

There has been described a gas flow control
process and novel swirl ring construction for reducing
the wear on an electrode of a plasma arc torch,
particularly a high power cutting torch, but in
general for all types of plasma torches, e.g. ones for
welding, spraying or other applications. The
invention, in any of its embodiments, can reduce the
wear that presently occurs on all electrodes to an
extent that the life of the electrode is at least
doubled and can be as much as ten times or more. The
invention allows a given torch to be operated at
increased power levels and with reactive gases. These

advantages can be achieved with no dimunition of cut
quality, and using standard electrodes and nozzles.
In fact, due to the discovery that the swirling flow
does not adversely affect the electrode wear during
cutting, and knowing that a strong swirl yields high
quality cuts, the swirl strength can now be increased
in torches to improve cut quality. Moreover, existing
plasma arc torches and complete torch systems can be
readily modified to use the present invention.

     While this invention has been described with
reference to its preferred embodiments, it will be
understood that various modifications and alterations
will occur to those skilled in the art from the
foregoing detailed description and the accompanying
drawings. For example, while the invention has been
described with respect to a swirl ring containing the
choke holes and a pre-chamber, these features could be
built into the torch body, components forming the
torch body, or other components such as even a portion
of the nozzle itself or a flange on a retaining cap.
The flow control concept of the invention, regardless
of the details of its implementation, is that a plasma
gas flow restriction is placed in the plasma gas flow
path immediately preceding the plasma chamber and a
small supply of gas is available downstream of the
restriction, but upstream of the plasma chamber.
These and other modifications and variations are
intended to fall within the scope of the appended
claims.

     What is claimed is:

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Claims:

1.   A process for controlling wear of an
electrode in a plasma arc torch at the termination of
a cycle of operation where an arc current and plasma
gas flow through the torch are cut off, and where the
electrode is mounted within a torch body opposite and
in a spaced relationship to a nozzle having an exit
orifice for a plasma arc, the electrode and nozzle
defining a plasma chamber, the torch body including
means for directing a flow of an ionizable gas through
the torch body to the plasma chamber, and the torch
body having a conductive path for an arc current to
produce a plasma arc in said gas flow eminating from
said electrode both as a pilot arc to the nozzle and
as a transferred arc to a workpiece at a full
operating arc current value, comprising
        creating a pressure drop in said flow of
ionizable gas immediately upstream of said plasma
chamber, said pressure drop being sufficiently low
that the gas flow into the plasma chamber at the full
operating value produces a gas pressure and gas flow
pattern in said plasma chamber that stabilizes the
arc, and
        said pressure drop being sufficiently large
that at said arc current cut off the gas pressure and
the gas flow through said plasma chamber decays
rapidly in coordination with the arc current cut off.

2.   The electrode wear control process of claim 1
wherein said creating of a pressure drop comprises
restricting the gas flow to the plasma chamber within
the torch.

3.   The electrode wear control process of claim 1
further comprising the step of producing a local gas
chamber in said gas flow between the point of said
pressure drop in the torch and said plasma chamber.

4.   The electrode wear control process of claim 3
further comprising distributing the ionizable gas flow
from said local gas chamber to said plasma chamber in
a flow pattern that is swirling.

5.   The electrode wear control process of claim 4
wherein said gas distributing also produces a
generally spatially uniform flow of said gas through
said plasma chamber.

6.   The electrode wear control process of claim 1
wherein said gas flow shutting off precedes the arc
current cut off by a very brief time interval in which
the gas held in said local gas chamber and the plasma
chamber stabilize the arc until it is extinguished.

7.   The elctrode wear control process of claim 6
wherein said arc current cut off is ramped down.

8.   A gas control swirl ring for a plasma arc
torch having a torch body that mounts a nozzle and an
electrode at one end of the body in a spaced
relationship that defines therebetween a plasma arc
chamber where an arc current conducted through the
torch body ignites a plasma arc in a flow of an
ionizable gas directed through the torch body to the
plasma arc chamber via a gas inlet passage produces a
plasma arc that transfers to a workpiece via an exit
orifice in the nozzle during operation in a
transferred arc mode, comprising

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a generally annular body having an upstream face in fluid communication with said flow of ionizable gas in the torch body and a downstream face in fluid communication with the plasma arc chamber,

a gas chamber formed in the body,

a plurality of gas inlet passages extending from said upstream face of the body to said chamber, said passages being sized to restrict the flow of ionizable gas to the chamber and thereby produce a pressure drop in the gas flow, and

a plurality of gas distribution holes formed in said body extending between said chamber and the plasma arc chamber to produce a swirling, generally uniformly distributed flow of gas in said chamber.

9. The swirl ring of claim 8 wherein said gas chamber comprises an annular recess formed in the outer surface of said body between said upstream and downstream faces.

10. The swirl ring of claim 9 further comprising an annular first sealing recess formed in said outer surface between said upstream face and first annular recess.

11. The swirl ring of claim 9 further comprising annular second and third sealing recesses formed in the upstream and downstream faces of said body.

12. The swirl ring of claim 8 further
comprising a plurality of radially directed holes
formed in said body extending from said gas chamber to
said an inner surface of said body extending between
said upstream and downstream faces and in fluid
communication with the plasma arc chamber.

13. The swirl ring of claim 8 wherein each
of said gas inlet passages and said gas distribution
passages are mutually equiangularly spaced and are at
least four in number.

14. The swirl ring of claim 8 wherein the
gas pressure in the plasma arc chamber during
operation is about 40 psi and said pressure drop is
about 32 psi.
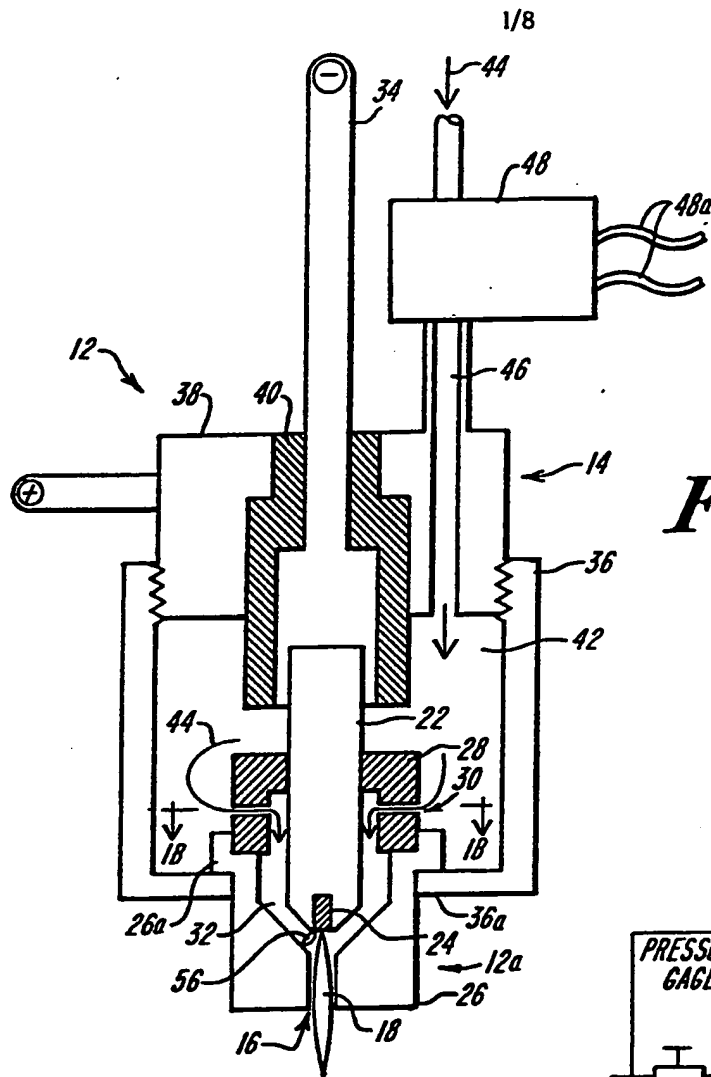
FIG. 1A
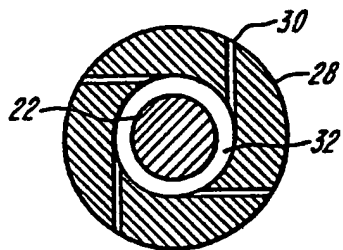
FIG. 1B
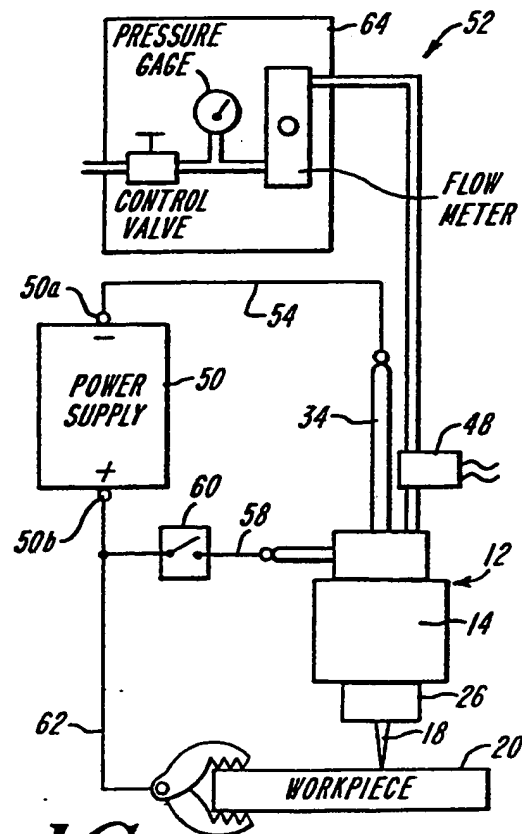
FIG. 1C

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FIG. 1D

FIG. 2A

FIG. 2B

FIG. 2C

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FIG. 3A

FIG. 3B

FIG. 3C

FIG. 3D

PRESSURE
GAGE

CONTROL
VALVE

FLOW
METER

PRESSURE
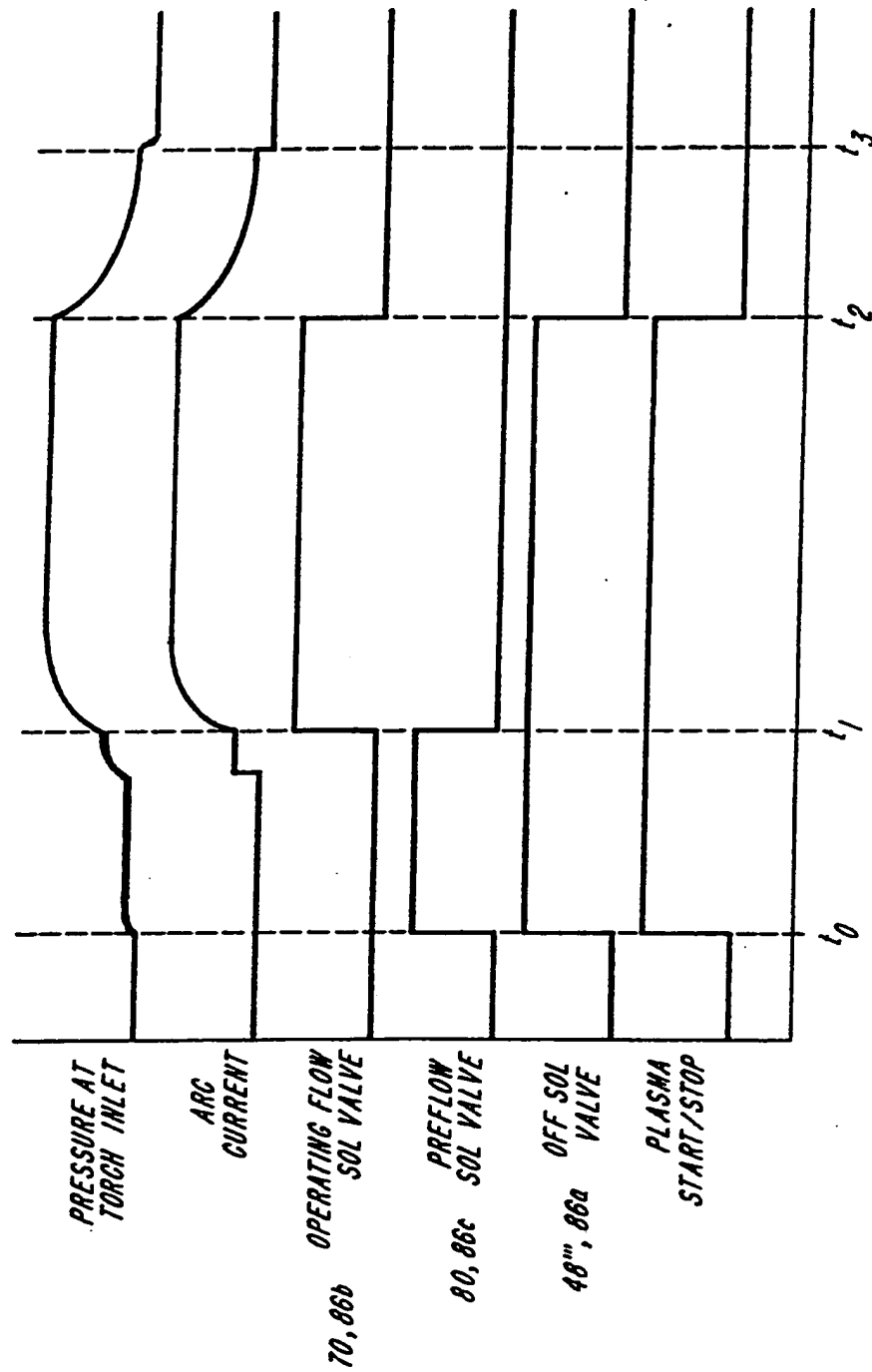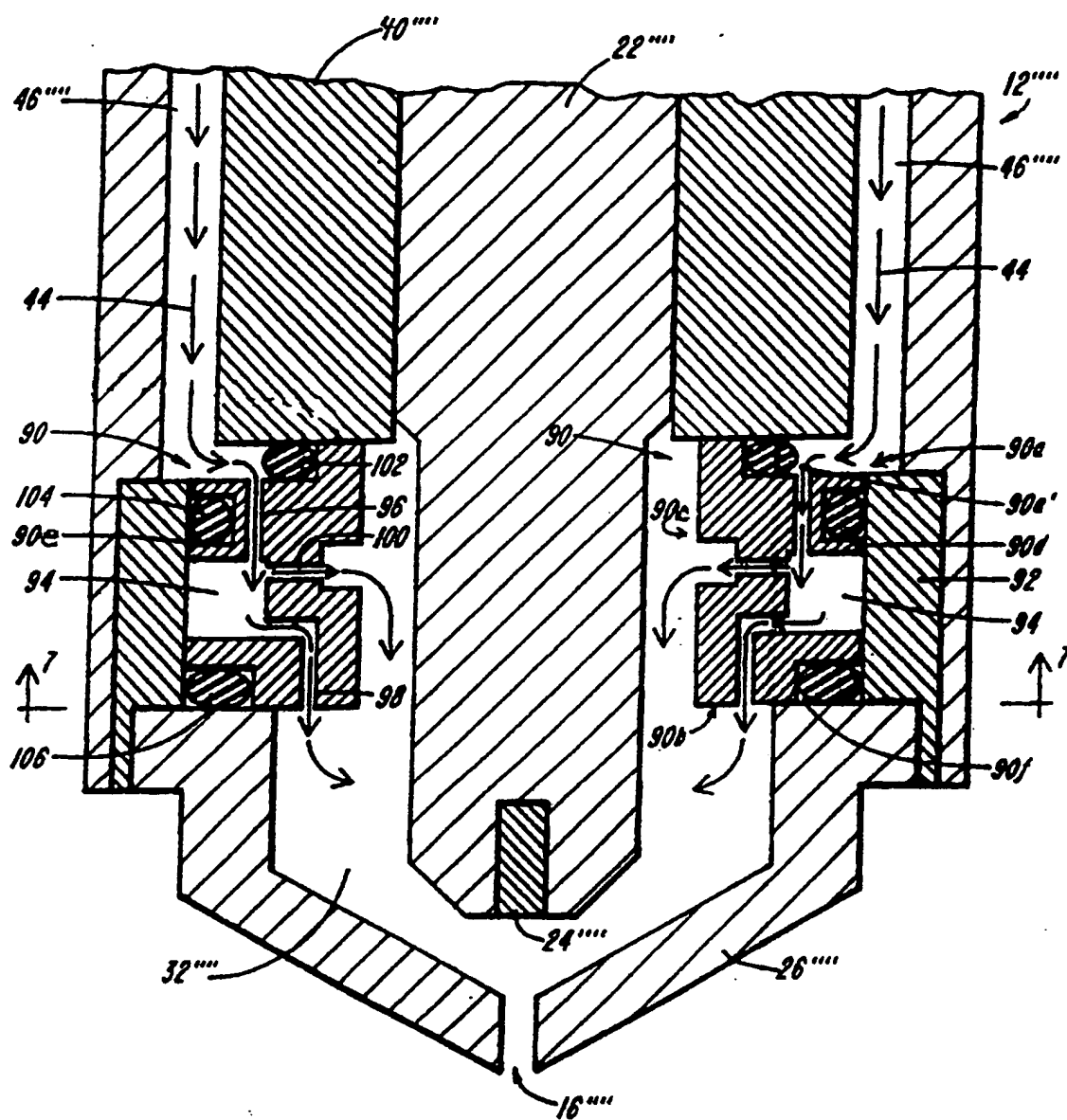GAGE

CONTROL
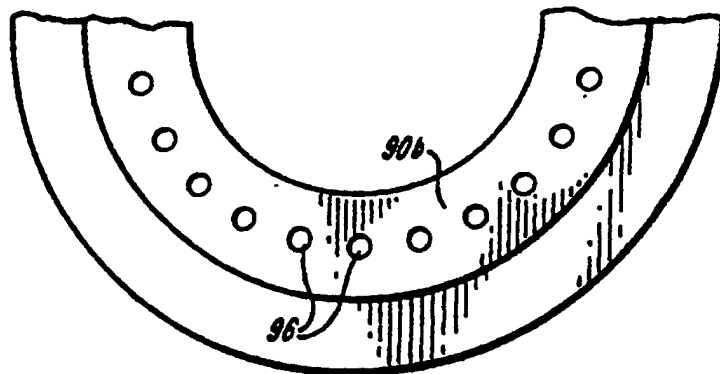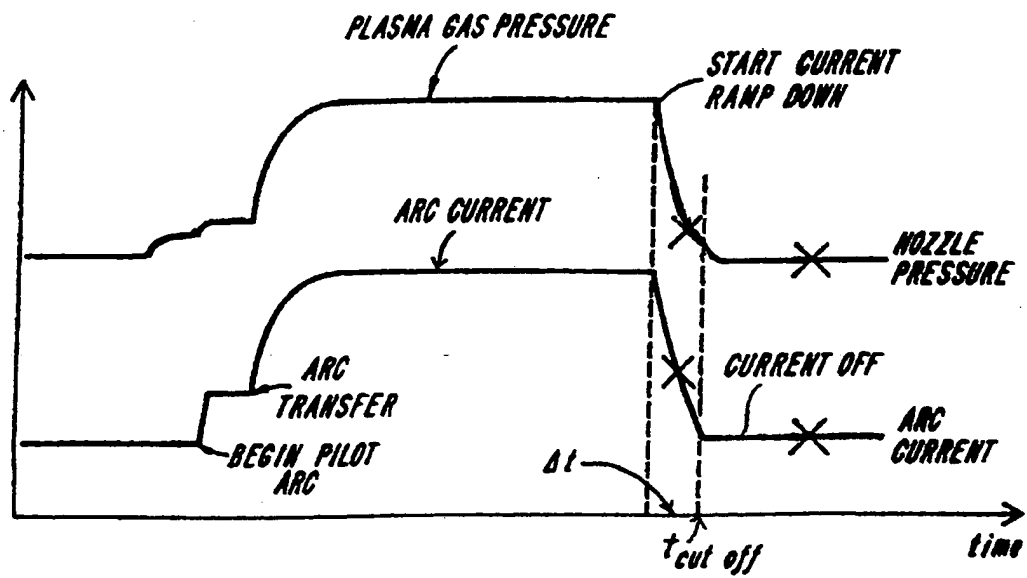VALVE

FLOW
METER

POWER
SUPPLY

WORKPIECE

FIG. 4

FIG. 5
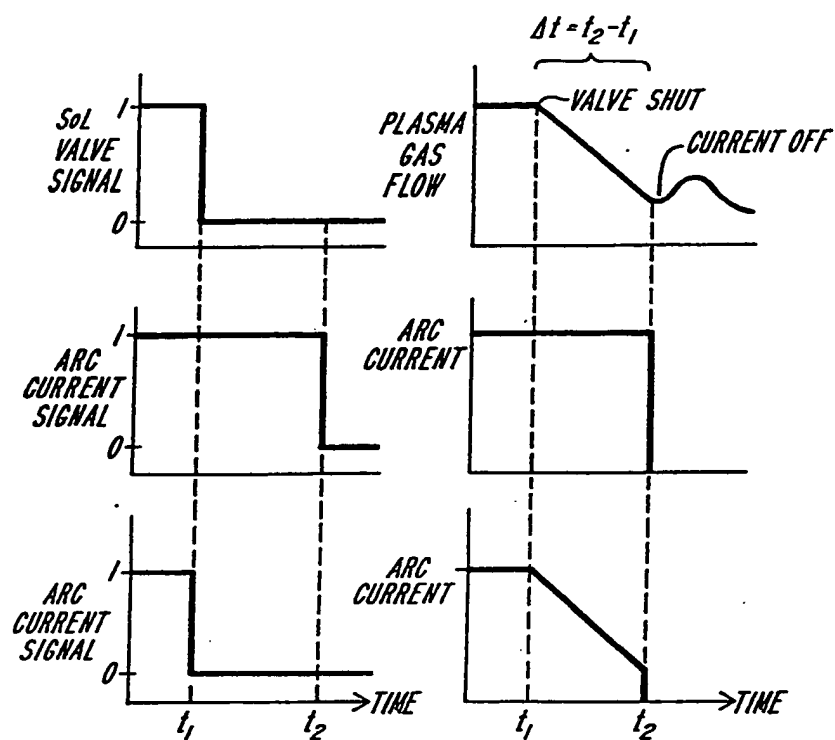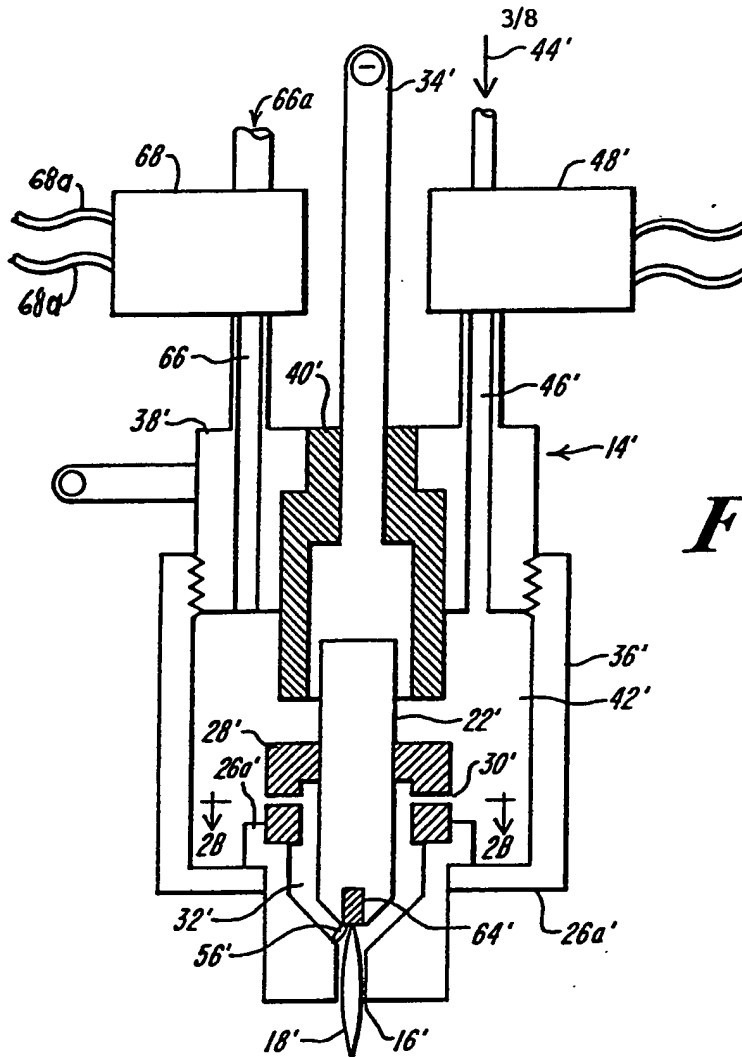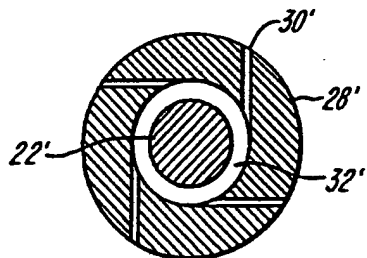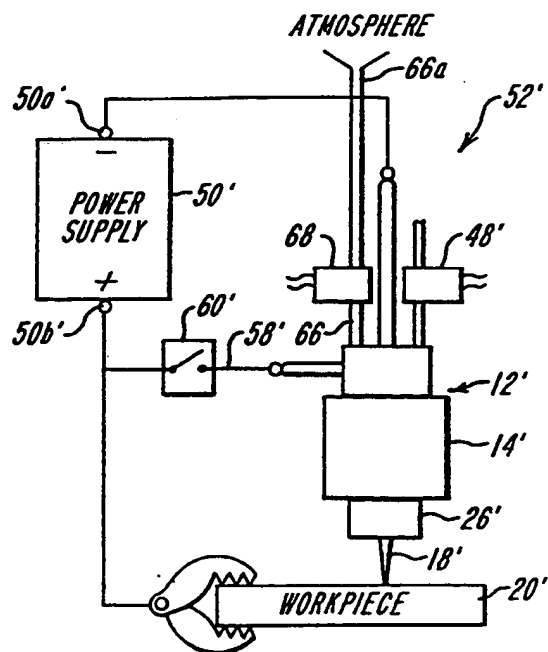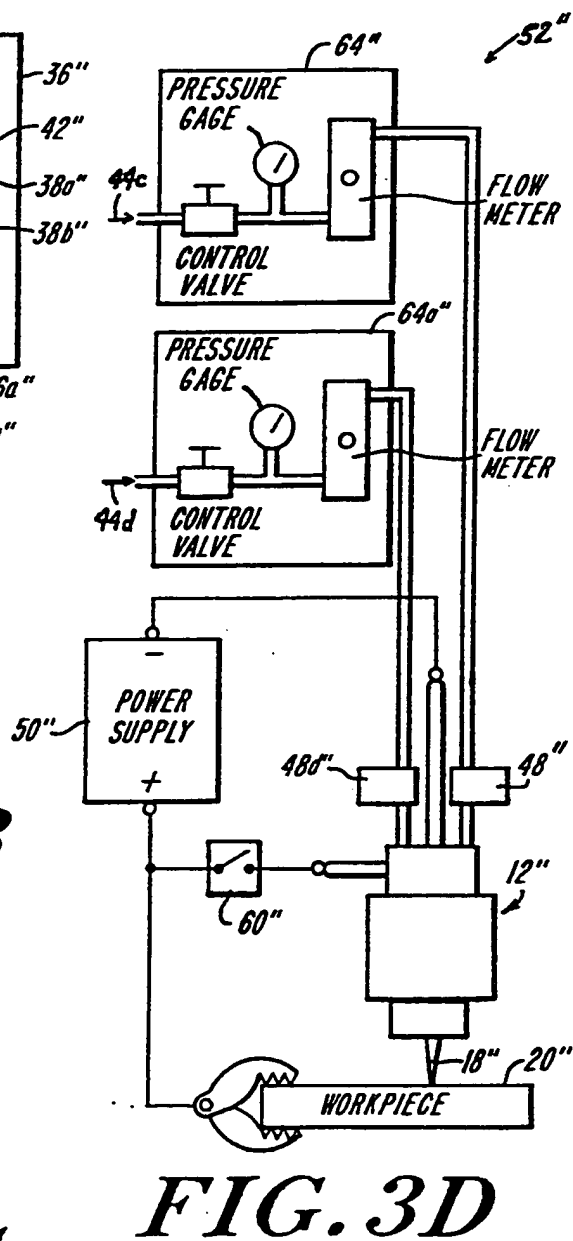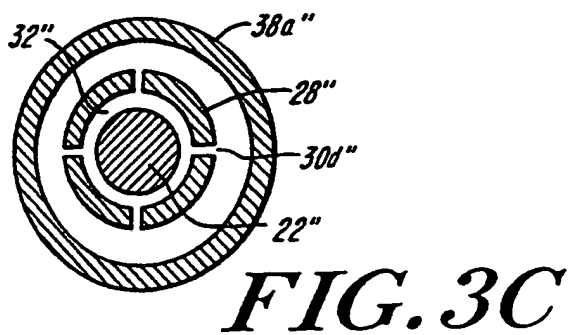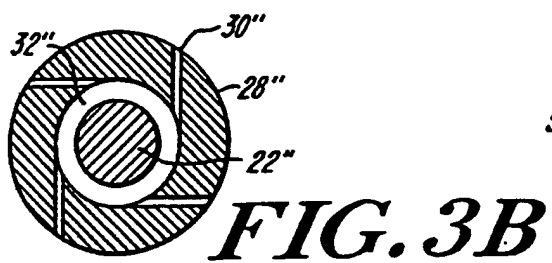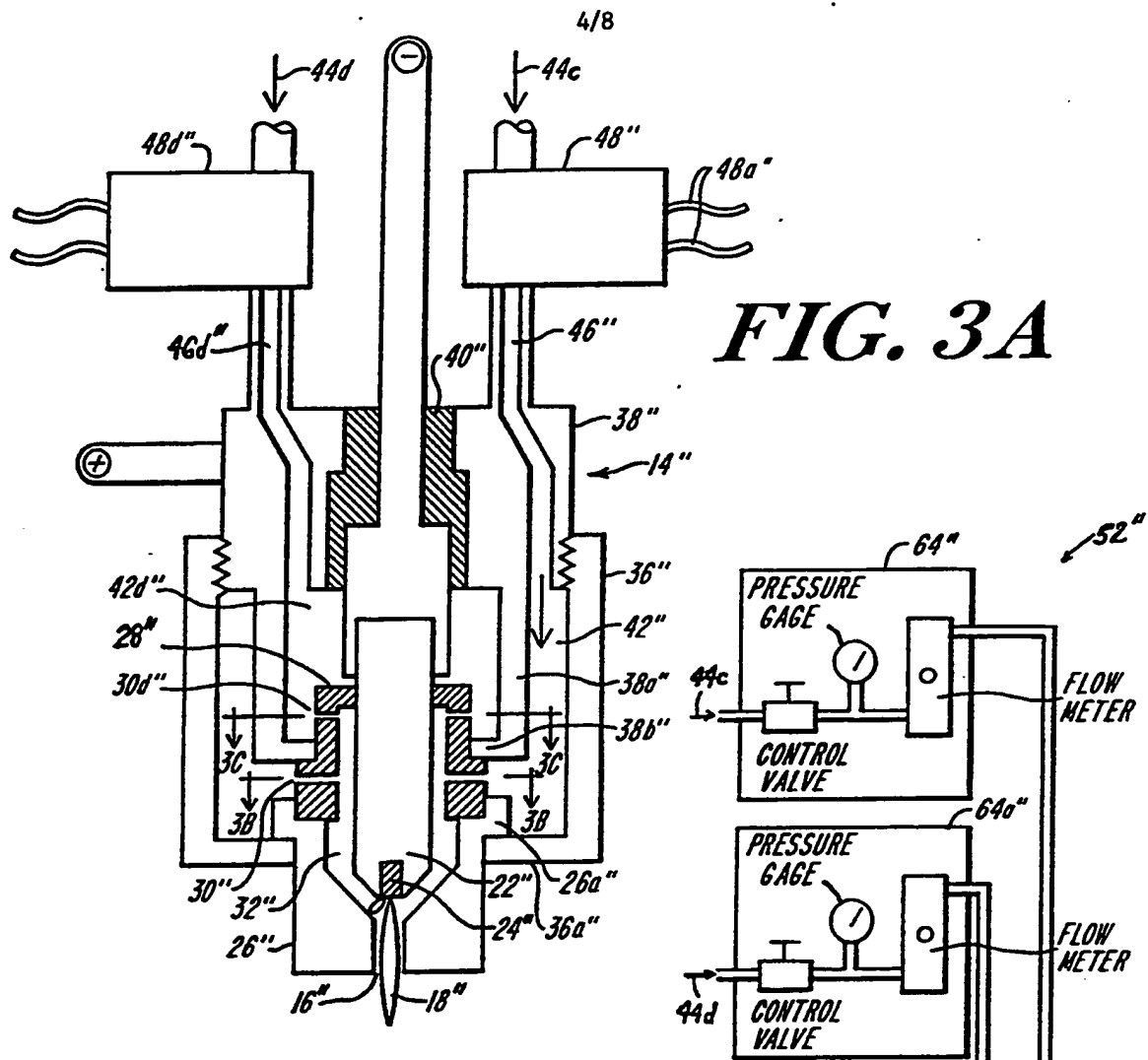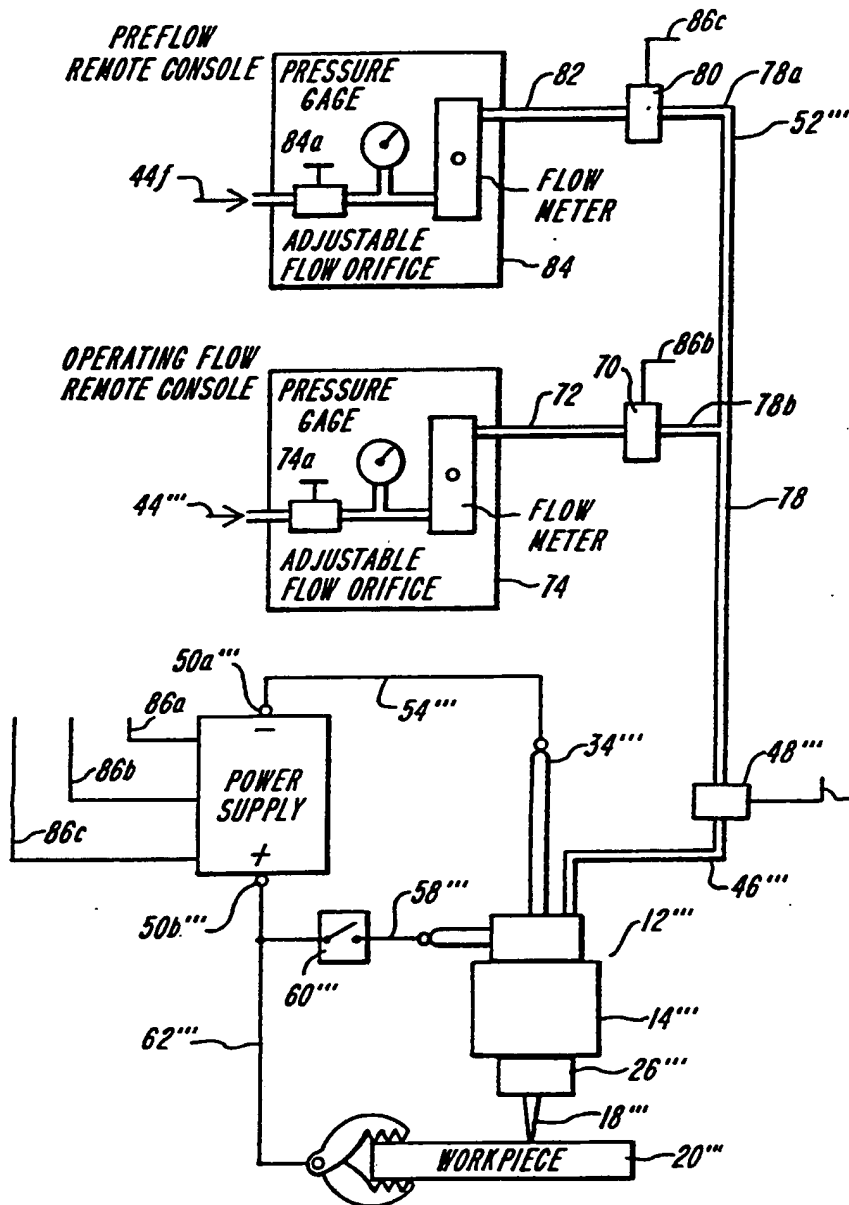
FIG. 6

FIG. 7

FIG. 8

INTERNATIONAL SEARCH REPORT

International Application No PCT/US91/02783

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) 6

According to International Patent Classification (IPC) or to both National Classification and IPC

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IPC (4):    B23K 9/00
U.S. CL:    219/121.55, 121.51, 121.59
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II. FIELDS SEARCHED

Minimum Documentation Searched 7

Classification System	Classification Symbols
U.S.	219/121.5, 121.51, 121.55, 121.54, 75 313/231.21 - 231.51

Documentation Searched other than Minimum Documentation
to the Extent that such Documents are Included in the Fields Searched 8

III. DOCUMENTS CONSIDERED TO BE RELEVANT 9

Category *	Citation of Document, 11 with indication, where appropriate, of the relevant passages 12	Relevant to Claim No. 13
X,P	US, A, 5,017,752 (SEVERANCE JR. et al) 21 MAY 1991 See entire document	1-11
X	US, A, 4,791,268 (SANDERS et al) 13 DECEMBER 1988 See entire document	1-11
A	US, A, 4,902,871 (SANDERS et al) 20 FEBRUARY 1990	1-11

* Special categories of cited documents: 10

"A" document defining the general state of the art which is not considered to be of particular relevance

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"P" document published prior to the international filing date but later than the priority date claimed

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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
20 JULY 1991	16 AUG 1991
International Searching Authority	Signature of Authorized Officer
ISA/US	M. H. PASCHALL

Form PCT/ISA/210 (second sheet) (Rev.11-87)